

# NASA/DoD Aerospace Knowledge Diffusion Research Project

## Paper Forty Two

*An Analysis of the Transfer of Scientific and Technical  
Information (STI) in the U.S. Aerospace Industry*

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# **AN ANALYSIS OF THE TRANSFER OF SCIENTIFIC AND TECHNICAL INFORMATION IN THE U.S. AEROSPACE INDUSTRY<sup>1</sup>**

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## **ABSTRACT**

The U.S. aerospace industry has a long history of federal support for research related to its needs. Since the establishment of the National Advisory Committee for Aeronautics (NACA) in 1915, the federal government has provided continuous research support related to flight and aircraft design. This research has contributed to the international preeminence of the U.S. aerospace industry. In this paper, we present a sociological analysis of aerospace engineers and scientists, and how their attitudes and behaviors impact the flow of scientific and technical information (STI). We use a constructivist framework to explain the spotty dissemination of federally funded aerospace research. Our research is aimed towards providing federal policymakers with a clearer understanding of how and when federally funded aerospace research is used. This understanding will help policymakers design improved information transfer systems that will aid the competitiveness of the U.S. aerospace industry.

## **INTRODUCTION**

This paper contains a sociological analysis of the transfer of scientific and technical information (STI) among engineers and scientists who work in the U.S. aerospace industry. The purpose of this paper is to describe a sociological framework for analyzing the flow of STI. Through an understanding of the production and dissemination of aerospace STI, we hope to provide policymakers with information and data that will improve STI dissemination. If successful, the results from this research will assist the U.S. aerospace industry in improving its international competitiveness.

Both basic and applied sociology are used to understand the production, transfer, and use of STI. The examination of the daily activities of aerospace engineers and scientists provides an understanding of the meaning and use of STI. This analysis is framed in the constructivist context based loosely on Latour's *Science in Action* (1987). As applied sociology, the paper demonstrates how the understanding of social forces that impact on the daily activities of aerospace engineers and scientists can be used to understand STI dissemination. Through this understanding, policymakers can develop more effective systems for the transfer of STI.

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## BACKGROUND

This paper is part of a five-year Project whose primary aim is to provide an understanding of, among other things, the information environment in which U.S. aerospace engineers and scientists work and the factors that influence their use of STI (Pinelli et al. 1993c). From this Project, we hope to understand the impact of federal policies on aerospace knowledge diffusion and to contribute to improvements in the transfer of aerospace research knowledge produced through federally funded research.

### **The NASA/DoD Aerospace Knowledge Diffusion Research Project**

The *NASA/DoD Aerospace Knowledge Diffusion Research Project* attempts to understand the uses and flows of information at the individual, organizational, national, and international levels in the aerospace industry. The Project focuses on the methods used by aerospace engineers and scientists to gather, evaluate, use, and communicate STI. The research is situated in multiple disciplines. Its researchers have specialties in sociology, information sciences, technical communications, and survey research.

The Project has four phases. Phase One examines the production and use of aerospace information by U.S. aerospace engineers and scientists. Phase Two examines how information intermediaries (principally librarians and technical information specialists) in the aerospace industry evaluate and disseminate technical information. Phase Three looks at aerospace engineering in academic settings, to include students, faculty, and information specialists. Phase Four examines the international dimensions of aerospace STI. A variety of surveys of aerospace engineers in western Europe and in Asia were conducted in this Phase (Pinelli et al. 1991a).

### **Federal Technology Policy and the U.S. Aerospace Industry**

The U.S. aerospace industry is a critical component of the national economy. Over the past 20 years, it has consistently been a net exporting industry (second only to agriculture) and has contributed significantly to minimizing the balance of payments deficits with other industrialized nations. The industry is a leader in advanced technologies. Most importantly, the aerospace industry provides well paid and highly-skilled jobs, the types of jobs most important for industrial and employment growth. Overall, the success of the aerospace industry is critical to the health of the U.S. economy.

The aerospace industry differs from other U.S. industries in that it is very dependent on government policies and programs. The U.S. aerospace industry has been described as a "sheltered" culture (Derian 1990), as opposed to an "exposed" culture, because the federal government has played a key role in the innovation and diffusion process. The aerospace industry has benefited from a variety of federal policies. For example, the federal government has supported the aerospace industry by providing essential research and development (R&D) activities needed to develop new civilian aircraft. In addition, the US government is a dominant purchaser of aircraft, primarily for the Department of Defense (DoD). The major US aircraft manufacturers produce both military and civilian aircraft. The design and development of defense aircraft have supported technology transfers and the establishment of production facilities that are

used to build civilian aircraft. In general, the design of civilian aircraft has benefited more from federal research and development for military aircraft than vice versa.

The federal government has long been involved in aircraft research. In 1915, Congress established the National Advisory Committee for Aeronautics, whose mission was "to supervise and direct the scientific study of the problems of flight, with a view to their practical solution" (Bilstein 1989, p. 4). In 1958, the activities of the NACA were transferred to a new federal agency, the National Aeronautics and Space Administration (NASA). Part of NASA's mission was "to plan, direct, and conduct aeronautical activities; to arrange for participation by the scientific community in NASA research; and to provide the widest practical and appropriate dissemination of information" (cited in Langford 1989, p. 12). NASA sponsors and conducts research crucial to the aerospace industry. According to Mowery (1985), the U.S. commercial aerospace industry is unique in that it has benefited from research conducted on airframe, engine, and production technologies. Other federal agencies, notably the DoD and the Federal Aviation Administration, fund and disseminate research used by the aerospace industry.

Sound economic and policy objectives are met through government-funded aerospace R&D. Langford (1989) notes that the government should fund R&D when negative economic incentives to the private sector result from the research. This problem occurs in aerospace because research costs associated with the development of new technologies are too expensive to benefit any one firm. When the federal government (usually NASA) conducts research, it provides public benefits that cannot be allocated equitably in the private sector. This research serves to stimulate the private sector and provide cost-efficient public benefits (Langford 1989, p. S-3).

In the past few years, the aerospace industry has suffered from the decreased funding for defense. These cuts, along with the decrease in airline travel triggered by a worldwide recession, have reduced the demand for new airplanes. In 1992 and 1993, shipments from U.S. aerospace companies decreased six percent and five percent respectively. As a result, the aerospace industry lost about 160,000 jobs from 1989 to 1992 (U.S. Department of Commerce 1993). This decline in the aerospace industry hurts national security, reduces the generation of new technology, and increases the negative balance of payments from the U.S.

More than most other industries, aerospace is truly international. One strategy to reduce the loss of U.S. jobs is for the U.S. aerospace industry to sell more aircraft to other countries by competing effectively in the international marketplace. The aerospace industry requires a strong technology and knowledge base to maintain and improve its international competitiveness (Pinelli et al. 1992a). In the 1990's, the U.S. aerospace industry remains in a strong position to compete internationally because of its scientific and technical strengths (Lopez and Vadas 1991), but these strengths will diminish with the globalization of technology and the increased speed of STI dissemination.

U.S. aerospace companies also cooperate internationally. They participate in joint ventures with aerospace manufacturers in other countries because all participating companies

benefit from them. Foreign aerospace companies desire access to the technology available in the U.S. aerospace industry. The U.S. aerospace industry benefits because the joint ventures provide access to markets in other countries. In many countries, the purchase of aircraft is part of a national economic development strategy, and U.S. aircraft manufacturers would be shut out if they did not have cooperative agreements with manufacturers in these countries. While technology transfer from the U.S. to other countries improves the likelihood for the success of these cooperative ventures for U.S. aerospace firms, the migration of U.S. aerospace knowledge and know-how is of great concern in international cooperation. In the long run, it may negatively impact the preeminent position of the U.S. aerospace industry.

The U.S. aerospace industry differs from its counterparts in other countries in the amount and types of government assistance it receives. In Europe, Airbus Industrie (AI) receives substantial support in the form of startup loans from the governments of Germany, England, France, and Spain (Office of Technology Assessment 1991). These governments also ensure that their national airlines will purchase new AI planes. Startup loans and purchase commitments are extremely important to aircraft manufacturers because these financial incentives allow producers to design and develop new aircraft without risking substantial losses. Japan, too, provides significant startup loans for new aircraft development. These countries see support for their aerospace industries as a form of industrial and employment policy (Office of Technology Assessment 1991). The effect of government policies is to create an environment in those countries where risks are minimized in terms of costs so that risks in terms of new technologies are more enticing. In effect, government support in these countries serves to increase their international competitiveness (Tyson 1992).

In the U.S., aerospace companies have traditionally benefited from spin-offs from the R&D activities conducted by NASA and the DoD. As the defense budget decreases in the U.S., DoD-funded research will decrease and will impact on the development of new aerospace technology. For the U.S. aerospace industry to maintain competitiveness, increased and more rapid dissemination of federally funded STI to the U.S. aerospace industry will be critical. The U.S. federal government supports the aircraft industry through support of aerospace R&D, but unlike direct supports provided by other governments, there is no guarantee that the R&D will be utilized by U.S. civilian aircraft producers. The *NASA/DoD Aerospace Knowledge Diffusion Research Project*, of which this paper is a part, is aimed at providing an understanding of the STI diffusion process.

### **The Role of STI in Aerospace R&D**

Success in the aerospace industry requires that organizations take significant risks during aircraft development. Ten years may elapse from the time the first plans for a new aircraft are drawn until the new aircraft is first delivery to an airline. During this time, the aircraft designers continually test their designs as well as incorporate new information available from external sources. The complexity and the uncertainty in aircraft development, along with the competitive nature of the marketplace, produce conflicting demands on aircraft designers. They must balance the need to incorporate new technology with the possibility that it may have unforeseen conse-

quences. Increased access to STI can reduce the possibility of error in these decisions and allow the aircraft to come to market more quickly and efficiently.

Ideally, a designer will have access to all public knowledge related to the aircraft system that s/he is designing. During the development period, research within and outside the organization is conducted. We can assume the designers access internal research. Federal policies support a system in which federally funded aerospace STI is assumed to be adequately disseminated, but the effectiveness of the dissemination in reaching the appropriate aircraft designers is not fully determined. In particular, there is little information on how effectively the results of federally funded aerospace STI diffuse to the U.S. aerospace industry where those who need the information can use it.

### **The Federal Aerospace STI System**

The federal government attempts to disseminate aerospace STI through a variety of sources and products. DoD and NASA technical reports that are produced through federally funded R&D and that are unclassified and publicly available are available through the National Technical Information Service (NTIS). NASA regularly holds conferences and workshops on various areas of technology and offers four information products designed to help aerospace engineers and scientists gain access to the STI needed to perform their professional duties. *STAR* (Scientific and Technical Aerospace Reports) is an announcement journal that contains bibliographic information and abstracts of technical reports produced by NASA and its contractors. *IAA* (International Aerospace Abstracts), published by the American Institute of Aeronautics and Astronautics (AIAA), contains bibliographic information and abstracts of "open literature" such as conference papers and journal articles in aerospace and related disciplines. *SCAN* (Selected Current Aerospace Notices), a current awareness publication containing bibliographic information and abstracts of technical reports and open literature publications in aerospace and related disciplines. *SCAN* is available on the Internet. *RECON* (REsearch CONnection) is the NASA online search and retrieval system. NASA uses considerable resources to make aerospace STI available to the U.S. aerospace community.

### **Models for Disseminating Federal STI**

The federal STI dissemination strategy is based on the assumption that the adequate documentation, cataloging, and availability of materials provide access to STI. The distribution system appears to provide sufficient documentation and cataloging of all relevant federally funded aerospace STI. Yet previous research conducted as part of this Project clearly indicates that the dissemination system is not fully utilized. The problems of disseminating federally funded R&D are well known and documented. (See, for example, Averch 1984; Mowery 1983; Tornatzky and Fleischer 1990.) Three models have been used (Ballard et al. 1989; Williams and Gibson 1990) to describe the dissemination of federally funded R&D. We can briefly summarize the aerospace research dissemination problems while describing these models.

The first model, the **appropriability model**, assumes that competitive market pressures will promote the search for and use of STI. In this model, the federal government does not need to create transfer mechanisms but assumes the STI will sell itself. The model ignores the

problem that most research is not relevant to most users, so it becomes difficult to determine which research is most appropriate when users need information to solve technical problems. The model also assumes the STI transfer channels and sources are identified and understood by users or that the STI will appear in the open literature, such as professional journals.

The current model in aerospace, the **dissemination model**, assumes the federal government must do more than generate STI. Merely producing information will not necessarily result in its transferring to those who need it. The dissemination model requires that mechanisms (such as *NTIS*, *SCAN*, and *RECON*) be available to link the STI users (e.g., aerospace industry engineers) with the producers (e.g., NASA and its contractors). This model is not fully effective because it is a passive system. Those who need STI must enter the system looking for information. The model assumes those who look for information have the resources necessary to find it in a cost-effective manner. Under this model, STI is produced to meet the needs of the producers, and little concern is given to the users of the information.

Both models assume certain attitudes and behaviors among the users of aerospace R&D that may not be correct. First, these models might be more appropriate for dissemination to scientists than to engineers. The models assume that the user will look for new, external information before or while working on a project, as a scientist will do. Second, these models do not recognize that users vary in their STI needs. Various factors, such as the type of engineering being done, influence STI use. For example, research engineers need different types of information than design or production engineers use. Corporate culture also influences use. In many companies, in-house materials are expected to meet the STI needs of most engineers. Third, the models fail to recognize that users are not trained in the use of STI channels and products. In various parts of this Project, we have examined these factors and found them to be substantially correct.

A more effective model, the **knowledge diffusion model**, stresses active intervention and reliance on interpersonal communications to achieve improved levels of STI transfer. In this model, the producers and users are linked, and STI products are tailored to the needs of the users. The dissemination of STI in agriculture and mental health is based on this model, and the model is closely aligned with TQM-style management procedures. Implementing the knowledge diffusion model in aerospace would be difficult currently because federal STI dissemination policies do not support this model. A more active federal role in supporting specific user information objectives is necessary for the implementation of the knowledge diffusion model.

Despite this problem, the knowledge diffusion model would best serve the policy goals that provide the justification for federally funded aerospace R&D. That is, the federal government funds aerospace R&D because the risks are high and the costs of much cutting-edge research are prohibitive for private sector organizations. However, this model requires a more thorough understanding of the producers and users of STI than is currently available if adequate diffusion of the results are to be achieved. An analysis of aerospace engineers and scientists can help determine why the dissemination model does not work and what must be understood about the participants in the STI generation and diffusion process to make the knowledge diffusion

model work. Basic sociology that analyzes the daily activities and the social forces that impact on engineers and scientists can help fill this information void. Applied sociology can help design a more effective STI diffusion process.

## **ENGINEERS AND SCIENTISTS**

The constructivist approach to scientific knowledge is used in this paper to analyze the activities of aerospace engineers and scientists. This approach assumes that scientific (and technical) knowledge is created, like any other knowledge, through the interactions of participants. Scientific knowledge is not based on "truth" but rather is created by scientists (and engineers) to construct understandings and explanations. The microsociological work of Latour (1987; Latour and Woolgar 1986) is a specific example of this approach. Latour recommends that to understand science one must "follow the actors." In this Project, we have followed the actions of the aerospace engineers and scientists as they describe how they use, create, and communicate technical information.

Latour (1987) used the term "technoscience" to describe both science and engineering. Success in technoscience results from the recruitment of other scientists (and engineers) into networks that accept the same explanations of empirical phenomena. Since, to constructivists, there are no scientific "truths" that exist apart from the interpretations given to them by the actors, the successful development of a network by recruiting allies is necessary for successful science. In the same manner, successful technology rests not only on the development of proofs of concepts but also in recruiting others to believe the interpretation of the explanation of why it works. For example, Vincenti's (1990) analysis of the Davis wing explains how recruitment can influence the acceptance and rejection of a new design.

Latour used the term "black box" to describe how the forces used in the recruiting of allies in science extend to the technical design of an artifact (1987, pp. 128-132) which results in successful science. He noted that research (basic) is "the first moment, and development is all the work necessary to make the black box work" (p. 169). The working black box in technoscience includes the building of a "machine" and the creation of the machine depends on the successful recruitment of the participants in a technoscience process into believing the machine is an organized whole of facts and artifacts. The machine represents the "taken for granted" explanations of how the artifacts function.

Latour argues that engineers and scientists are hard to distinguish from each other in technoscience. They differ by title, training, and tasks, but when we analyze them as part of technoscience, they differ only by where they fit into the recruitment process. Other researchers agree with Latour that engineers and scientists are similar. Citro and Kalton (1989) provide multiple methods of defining engineers and scientists as a group for statistical purposes, but none of their definitions fully encompasses both self-identification and actual daily activities. Numerous researchers have described the differences between engineers and scientists. Pinelli et al. (1993a, pp. 174-185) review much of this literature. Little of this research provides

empirical justification for the differences ascribed to engineers and scientists, but to be fair, the research generally focused on other topics. In aerospace, perhaps as in other industries, it is difficult to classify many of the participants as either engineers or scientists, despite their occupational self-identification.

Examining aerospace requires that we distinguish the professions of engineers and scientists from the activities of engineers and scientists. We need to focus on science and technology as they actually happen. In aerospace, science and engineering are aimed towards the innovation and development of new technologies. The process of innovation and technology development is based primarily on STI and its movement. Science and technology may be closely connected in some instances, distantly in others, depending on the information flows. To understand the connections (both strong and weak) in aerospace, we need to examine the activities of those who classify themselves as engineers and scientists.

Engineers and scientists build machines through technical communications. For the most part, very few aerospace engineers and scientists actually build an artifact. They work in research, design, and development, and they do it using communications and computers. For example, the Boeing 777 was the first airplane built without an actual mock-up of parts. Rather, it was designed fully on computers. Multiple firms in multiple countries contributed to its design and development primarily through communications. It is through an understanding of the use of STI and its transfer that we can see how machines are built. Successful machines require successful recruitment, which in turn is based on STI dissemination.

In our research, the focus is on the behaviors and attitudes of the actors -- engineers and scientists -- and not on the outcomes -- science and technology. While Latour says they are connected as part of technoscience, other researchers believe that science and technology are not as closely related. Shapley and Roy (1985) argue that a progression of ideas from science to technology does not exist and that there is little communication between them. Allen (1977) found that there was little interaction between science and technology and that interactions developed only when the need arose. That is, engineers do engineering until engineering does not provide a solution to a problem. Only then do they look to science for a solution. While we have no disagreement with their research, we believe that this disconnect between engineering and science need not exist and that it is possible to link the two more closely through improved dissemination of technical communication.

Both engineers and scientists spend a significant portion of their daily activities creating and using STI. We broadly define STI here to include not only printed materials, such as journal articles and technical reports, but also other STI products, such as designs and computer programs. All of these components are needed to create a machine. The traditional distinctions between engineers and scientists are partly responsible for the shortcomings of the current STI dissemination system, and by thinking differently we can observe the STI dissemination system from a different angle. We propose that it is more fruitful to look at engineers and scientists in terms of their "enrollment" behaviors in technoscience to achieve our goal of developing an understanding that will allow the design of a better system for diffusing STI.

Let us provide a brief summary. Engineers and scientists share some common behaviors, but the focus of their work differs significantly. The goal of scientists is supposedly to create "facts"; the goal of engineers is supposedly to create "artifacts." To be successful, each needs to find, use, create, and communicate information. But the definition of success differs for each. Scientists desire the acclaim of peers and recognition of priority of discovery (Taylor 1986). Engineers are more directly involved in organizations and seek rewards (monetary, better projects) within the organization. The organization is successful when the "artifacts" engineers produce succeed in the marketplace. But both engineers and scientists are similar in that success depends on the ability to use STI effectively both as consumers and as producers. "Recruitment" leads to success and is accomplished through STI activities.

The different orientations lead to different day-to-day behaviors in the use of STI, but each group's behavior is part of the process of technoscience. A significant difference exists between the purpose for recruitment activities of engineers and scientists. From a science perspective, scientists want to recruit others, including engineers, into the networks that they develop. From an engineering perspective, engineers need to recruit others, often scientists, to justify their design decisions. The process of recruitment becomes especially critical when engineers encounter significant problems related to technical complexity and uncertainty. In aerospace, the enrollment process goes both ways, and when it occurs successfully, both groups benefit.

When we look at the dissemination of aerospace STI to see how well it fits Latour's description of technoscience, we see that the critical connections are not clear and open. Latour's model does not work effectively for two reasons. **First**, the STI dissemination channels that are needed for recruitment are not well designed or developed. **Second**, aerospace STI is used differently than Latour's model predicts. He believes that recruitment goes from science through engineering to make black boxes happen. In fact, recruitment goes in both directions, from scientists (in NASA research centers, for example) who need to recruit engineers working in industry, and from engineers in industry, who need to use NASA research to validate their designs. STI should be the common link by which engineers and scientists enroll others into their interpretations of the empirical world. The link is not clearly available in aerospace, and its unavailability causes problems for both the producers and users of STI.

## METHODS

Multiple surveys were conducted as part of this Project. For this paper, we use data from a mail survey of members of the American Institute of Aeronautics and Astronautics (AIAA) (Pinelli et al. 1991b), a telephone survey (Pinelli et al. 1992b) and a mail survey (Pinelli et al. 1993b) of persons involved in aerospace provided by the Society of Automotive Engineers (SAE), and a telephone survey of NASA engineers and scientists working in five NASA research centers (Glassman and Pinelli 1992). Each group provides a different focus for the use of STI. We select data from these studies to provide evidence for the assertions made in this paper. Each group was chosen to represent a different portion of the technoscience continuum. The NASA

engineers and scientists at the five NASA research centers, despite their titles, focus on aerospace research and might be considered as scientists. The AIAA is a professional society composed of aerospace researchers. Its membership includes aerospace engineers and scientists who conduct engineering research. About one-third of its members hold a Ph.D. (Pinelli 1991). Relatively few design and development engineers belong to the AIAA. The SAE has an aerospace division that serves primarily design and production engineers. The three groups represent three-fourths of the aerospace science-engineering spectrum. (The last group - manufacturing and production engineers in aerospace - were surveyed this summer.)

## **DATA**

We describe our data analysis in a narrative form because the data are taken from multiple parts of the Project. These data were collected for various specific purposes, generally to answer a question about the STI dissemination system. As we now look at the various pieces contained in each survey (and the other surveys conducted in the Project), we start to see the overall system more clearly.

The STI dissemination process involves many aerospace engineers and scientists in multiple activities. In the next three sections, we look at some of the activities. First, we examine the time aerospace engineers and scientists spend in activities related to producing and using STI. Next, we demonstrate a gap between the design of the STI dissemination system and its actual use by aerospace engineers and scientists. Finally, we look at differences between the three groups in their production and use of STI. From these data, we summarize that the dissemination of STI is not working effectively.

### **Technical Communications**

Following the aerospace engineers and scientists in action requires that we examine their daily activities. We assert that they spend considerable time using STI in its various forms. In the SAE mail survey, we asked the respondents to estimate the average number of hours they had spent each week over the past six months using and producing technical communications. The respondents reported that they had spent about 18 hours each week communicating technical information and about 13 hours per week using technical information produced by others. There were no substantial differences in hours between those who reported research and those who reported engineering design or production as their primary professional activities. These estimates agree with those reported in an earlier study of AIAA members (Pinelli et al. 1989). Therefore, despite the type of science/engineering that characterizes the respondents' work, they reported an equal number of hours creating and using STI. The respondents may have overestimated the hours they spend on technical communication, but when they reconstruct their daily lives, they feel that this activity is the one they do most often. These numbers support our assertion that STI production and use are the primary activities of both aerospace engineers and scientists.

## **Dissemination of NASA STI**

NASA provides multiple formats for informing users and technical information specialists about recent aerospace STI. *STAR* and *RECON* are products designed to be used directly by those who need information, such as engineers in the aerospace industry. Unfortunately, these products are not used often, especially among design/development engineers. Approximately 40 percent of research engineers and scientists (AIAA members) use *STAR* and about 22 percent use *RECON*. Among design/development engineers, only 19 percent and 8 percent report using *STAR* and *RECON*, respectively.

These products are not used (Pinelli et al. 1994) for a variety of reasons, but the reason mentioned most often by engineers and scientists is that *STAR* and *RECON* are not available or accessible. The results from our surveys demonstrate one of the principal problems with the current STI dissemination system. From the federal perspective, these products (*STAR* and *RECON*) are expected to provide quick and easy access to bibliographic information on recently released STI. But in fact, these products do not fulfill their purpose (demonstrated by the small proportions of engineers and scientists who use them) and are considered inaccessible by those for whom the products are intended.

Without this key link between STI producers and users, the dissemination process cannot function rapidly or effectively. These information products should link STI producers, especially those whose research is federally funded, to the targeted users -- the engineers in aerospace firms. The current STI diffusion model in aerospace, which relies primarily on products and secondarily on intermediaries (technical information specialists) to link the producers and users, is not working. We think it is not working because the assumptions of the needs and behaviors of the STI users have not been determined. STI is critical to the recruitment process, and it appears that in aerospace this process is sporadic and uneven because the links are neither open nor clear.

## **Production and Use of Aerospace STI**

In this section, we compare the attitudes of the three groups towards the production and use of STI. One survey examined the production and distribution of STI from the perspective of NASA technical employees at five NASA centers. These employees classify themselves primarily as engineers (70 percent) and as scientists (23 percent), but they believe that the production of aerospace STI is an important part of their duties. Over 75 percent of the respondents to this survey indicated that it was important for them to publish scientific or technical information. Both from the perspective of the NASA mission and from their attitudes towards publishing in the open literature, the NASA technical employees we surveyed believe they are expected to produce STI.

The SAE respondents were primarily design/development engineers working in aerospace firms. Almost 70 percent agreed with the statement that the primary goal of scientists in aerospace is to generate and publish new information. Over 95 percent agreed that the primary goal of engineers is to design or improve a product or a system. Only 35 percent said their jobs required them to make contributions to aerospace literature. Although they spend substantial work time dealing with STI, they don't feel that producing open literature is an important part

of their professional responsibilities. They differ substantially from the NASA technical employees in their orientation to the production of aerospace STI.

There are also differences in the use of information sources among the groups. From the AIAA survey, we have responses to questions on the number of information products and the types of STI used. Respondents employed in government agencies (mostly in NASA) had used many more journal articles than industry employees in the six months prior to the survey. In contrast, industry respondents were more likely to use in-house technical reports. We found that external STI is more important to the engineers under conditions of uncertainty. SAE respondents reported that as the amount of complexity and uncertainty increased in a project the more important they thought it was to obtain external STI and the more likely they were to use the results from federally funded research during their most recent technical project. As complexity increases, the recruitment process of engineers increases. An effective STI dissemination system would enhance the recruitment process.

## SUMMARY

Much research on STI dissemination activities assumed that engineers and scientists are similar in their information needs. The similarity lies in the reasons for using STI -- to build networks and recruit allies in documentation of their constructions of interpretations of the physical world. Differences exist in the timing and use of STI, differences which appear to be based on the different ways different groups seek STI. Scientists use STI to start the discovery process. Engineers use STI as needed to develop a product or process. Scientists need STI to establish credibility for their arguments. Engineers need STI when their engineering skills, tacit knowledge, and internal STI do not provide enough information to reduce complexity or uncertainty in their designs. Engineers prefer internally-generated STI, but the more uncertainty in a design, the more likely engineers are to look outside the organization.

Latour described the multiple connections between engineering and science in the development of the diesel engine (1987, pp. 104-132). We expect similar connections based on knowledge transfers among engineers and scientists in aerospace, but in aerospace these connections are often weak. These loose connections do not imply that Latour is wrong. Rather, our data indicate that there may be separate and parallel engineering and science processes in aerospace that intersect only at very important junctures in aircraft design. Recruitment of allies for both groups does not often require recruiting from the other group. For the most part, this system has worked well, as evidenced by U.S. dominance in aerospace.

At the same time, we need to think about paradigm shifts that occur in both aerospace engineering and science. When they occur, as Constant (1980) pointed out in describing the turbojet engine, the thinking about design changes quickly. If U.S. aerospace companies are not tied to information that contains the paradigm shifts, the companies could suffer competitively. Because of the incredible technical complexity inherent in modern aircraft, paradigm shifts in various segments of aircraft design (e.g., avionics, acoustics, and engines) need to be constantly

monitored. These paradigm shifts may not be as momentous as the acceptance of plate tectonics by geologists (Stewart 1990), but they may be very important to more cost-effective aircraft design.

The aerospace industry is a critically important part of the U.S. economy for both employment and exports. Effective diffusion of STI that results from federally funded R&D is critical to the success of the aerospace industry. In the current economic and information environment, important information generated in technoscience requires quick dissemination before its value is lost. Therefore, it is critical that federal policies support the creation of STI diffusion systems that facilitate the adoption of new technologies (paradigm shifts) in the U.S. aerospace industry. In the rapidly changing technical world, new paradigms, or what Vincenti (1990) terms "radical designs," should appear more often. If these designs are diffused and implemented properly, they will provide a competitive advantage for those who use them.

Our research indicates that more thought must be given to the social context of engineers and scientists when designing an STI system. For example, using the work of Giddens (1979, 1984), one could examine the social structural conditions that impact on engineers' and scientists' decisions to use STI and the creation of aircraft designs that recreate the social structure. An analysis of engineering education might further determine how the social structure related to engineering work is recreated.

The design of an improved aerospace STI dissemination system requires input from various disciplines. Sociology can be used in an applied setting to assist policymakers in designing an STI dissemination system that addresses national needs. From our analysis, it appears that NASA and other federal agencies should move towards the implementation of the knowledge diffusion model described earlier. If STI producers could be more closely linked to STI users, more rapid STI transfers could occur. More importantly, better focused STI activities could be developed, because the needs of those who create the knowledge (engineers and scientists) could be integrated with the needs of STI users.

McDonnell Douglas estimates that it will cost \$1 billion to redesign just the wing for the airplane that will replace the DC-10 (Nelson and Rosenberg 1993). Two questions arise. First, has research already been done but not identified that would allow McDonnell Douglas to reduce its research costs and be more competitive? Second, if such research has been done, is there a system in place that will provide the information to McDonnell Douglas?

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